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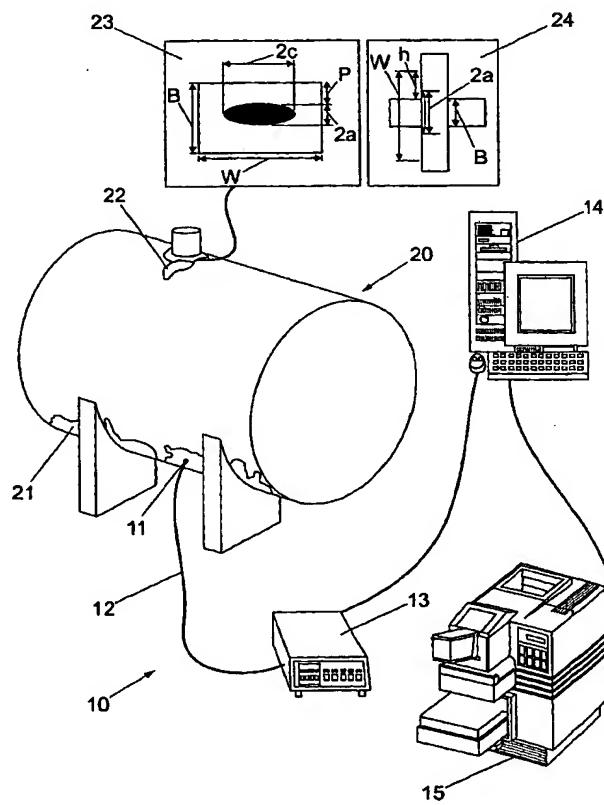
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[Continued on next page]

(54) Title: METHOD FOR ASSESSING THE INTEGRITY OF A STRUCTURE

(57) Abstract: A method for assessing the integrity of a structure, comprising the steps of: i) collecting data relating to the initial dimensions of the structure, ii) creating a computer model of the structure, iii) collecting data relating to the estimated load on the structure, iv) analysing the structure, using the computer model of the structure and the load data, in order to define areas which are subject to relatively high stress, v) measuring, after a time interval, the dimensions of the structure in high stress areas, vi) updating the computer model of the structure, using the results of step v), re-analysing the structure, using the updated computer model and the load data, in order to calculate a value for the integrity of the structure.



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1       Method for Assessing the Integrity of a Structure

2

3       The present invention relates to a method for  
4       assessing the integrity of a structure. The method  
5       according to the present invention involves the  
6       measurement of the dimensions of the structure and  
7       the loading and thereafter analysing the results of  
8       those measurements in order to calculate a value for  
9       the integrity of the structure.

10

11      In the process industry, one of the biggest sources  
12      of failures and shutdown for process plants is in  
13      pressurised piping and vessel systems. In the prior  
14      art, systems are known which monitor and assess  
15      plants in order to be able to predict a failure.  
16      According to the prior art, the wall thickness of  
17      structures, such as piping, is simply monitored in  
18      order to perform simple calculations and to predict  
19      a trend, for instance in the wear and/or the  
20      corrosion of such a structure. Alternatively,  
21      machinery-based corrosion and vibration monitoring  
22      systems are used. These systems are grossly

1 inaccurate as over 85% of failures occur at non-  
2 straight pipe areas, due to structural loadings,  
3 corrosion/erosion, fatigue, pulsation or vibration  
4 ("Hydrocarbon" magazine). The monitoring and  
5 assessment technologies according to the prior art  
6 are based on "risk analysis". These systems use  
7 probability to estimate failure, and in doing so  
8 predict suitable inspection intervals. An important  
9 disadvantage of such an approach is that these  
10 systems do not use real-time measurements in order  
11 to calculate real-time load and load changing  
12 mechanisms.

13

14 A system for monitoring a pipe segment for instance  
15 is known from the European Patent Application EP  
16 0358994. The method according to EP 0358994 is  
17 adapted to measure a corrosion/erosion trend. The  
18 system is confined to the change in the main pipe  
19 wall thickness to predict the future thickness of  
20 the pipe wall. According to this document the  
21 emphasis is on measuring the corrosion/erosion rate  
22 and using statistical techniques to predict future  
23 rates and trends. The estimated stress in a pipe  
24 wall is calculated using the following equation:

25

26 
$$\text{Stress} = \frac{\text{pressure} \times \text{radius}}{\text{thickness}} \times \text{estimated factor}$$

27

28 This equation only calculates pressure loading in  
29 straight pipes. No other loadings are considered.  
30 As the thickness decreases there is a danger of  
31 pipewall rupture. Therefore the information is used  
32

1       in order to predict the maximum time interval before  
2       the next inspection of the pipe welds. The  
3       information collected according to EP0358994, in  
4       practice, is not very helpful, as very few plant  
5       failures are caused by main pipewall rupture. This  
6       means that the information collected by means of  
7       EP0358994 has only limited value.

8  
9       Additionally, according to the prior art it is known  
10      to use acoustic pulsation, vibration and condition  
11      monitoring in order to monitor and assess the  
12      integrity of a structure. The disadvantage of those  
13      techniques is the fact that those techniques are  
14      both specialist tasks and extremely expensive.  
15      Because of the high costs involved with those  
16      techniques normally these techniques are only  
17      undertaken if failure is expected or has occurred.

18  
19      In view of the disadvantages and limitations of the  
20      methods for assessing the integrity of a structure  
21      according to the prior art, it is an object of the  
22      present invention to provide a method according to  
23      the introduction wherein load-changing mechanisms  
24      and dimension changing mechanisms, as they occur,  
25      are taken into account in the calculations of the  
26      integrity of the structure.

27  
28      To obtain these objects, the method according to the  
29      present invention comprises the steps of:

30  
31      i)     collecting data relating to the initial  
32      dimensions of the structure,

- 1       ii) creating a computer model of the structure,
- 2       iii) collecting load data relating to the estimated
- 3              load on the structure,
- 4       iv) analysing the structure, using the computer
- 5              model of the structure and the load data, in
- 6              order to define areas which are subject to
- 7              relatively high stresses,
- 8       v) measuring, after a time interval, the
- 9              dimensions of the structure in high stress
- 10             areas,
- 11      vi) updating the computer model of the structure,
- 12              using the results of step v),
- 13      vii) re-analysing the structure, using the updated
- 14              computer model and the load data, in order to
- 15              calculate a value for the integrity of the
- 16              structure.

17

18      In the present description the wording "computer  
19      model" is used. The wording "computer model" refers  
20      to a data set representing a structure, which data  
21      set can be analysed by means of an appropriate  
22      finite element analysis technology. By means of  
23      this finite element analysis technology the strains  
24      and stresses occurring in the structure can be  
25      calculated.

26

27      In the present description reference is made to "a  
28      value for the integrity of the structure". The  
29      wording "value for the integrity of a structure"  
30      refers to whether a structure is "fit for service"  
31      or not. When the value for the integrity of a  
32      structure is calculated, it is assessed whether the

1       structure is fit to perform its normal tasks. That  
2       means that the value for the integrity of a  
3       structure can refer to a minimum wall thickness, a  
4       maximum stress in the material of the wall, a  
5       maximum strain in the material of a wall, or similar  
6       feature.

7

8       According to the present invention data relating to  
9       the initial dimensions of a structure are collected.  
10      These data are used to create a computer model of  
11      the structure. That means that it is possible to  
12      use a finite element method in order to calculate  
13      strains and stresses in the structure. Thereafter  
14      data is collected relating to the estimated load on  
15      the structure. By means of the finite element  
16      method the structure can then be analysed, using  
17      both the computer model and the load data. The  
18      result of this analysis is that individual areas can  
19      be defined which are subject to relatively high  
20      stresses. Because of the fact that the high stress  
21      areas are identified, it is clear in which areas of  
22      the structure future problems can be expected.

23

24      If the results of the analysis of the structure  
25      reveal that the strains and stresses in the  
26      structure are within safety limits, the structure  
27      thereafter can be used for its normal purpose.  
28      After a set time interval the dimensions of the  
29      structure will be measured in the high load areas.  
30      Because of the fact that high load areas have been  
31      defined, the amount of measurements can be limited.  
32      That means that the actual measurement of the

1 dimensions of the structure in the high load areas  
2 involves relatively limited effort.  
3 Using the measured dimensions of the structure it is  
4 then possible to update the computer model and to  
5 re-analyse the structure. This calculation will  
6 result in an updated value for the integrity of the  
7 structure. This means that the method according to  
8 the present invention presents an efficient and  
9 effective method for assessing the integrity of a  
10 structure.

11

12 According to the present invention the method may  
13 further comprise the step of:

14

15 viii) repeating one or more times steps v), vi) and  
16 vii).

17

18 According to the present invention it is possible to  
19 continuously measure the dimensions of the structure  
20 in high load areas. Steps v), vi) and vii) can be  
21 repeated after a set time interval, which time  
22 interval may be dependent on the calculated value  
23 for the integrity of the structure in a former  
24 analysis.

25

26 According to the present invention the method may  
27 comprise the further step of:

28

29 ix) visualising the results of vii).

30

31 The method according to the present invention is  
32 suitable for continuously assessing the integrity of

1       a structure. In order to facilitate the review of  
2       the outcome of the assessment, the results of the  
3       calculations leading to the value for the integrity  
4       of the structure can be presented, for instance, in  
5       a table. This table can be presented to a plant  
6       manager who thereafter can take necessary actions,  
7       if needed.

8

9       According to the present invention the method may  
10      comprise the further steps of:

11

- 12      x) measuring the actual load on the structure,
- 13
- 14      xi) updating the data relating to the load on the  
15       structure, and thereafter
- 16
- 17      xii) re-analysing the structure, using the computer  
18       model and the updated load data, in order to  
19       calculate a value for the integrity of the  
20       structure.

21

22       The method according to the present invention cannot  
23       only be used for assessing the actual dimensions of  
24       the structure, the method is also suitable for  
25       measuring the actual load on the structure and using  
26       the results of those measurements in order to refine  
27       the calculations of the value for the integrity for  
28       the structure.

29

30       According to the present invention the method may  
31       comprise the further step of xiii) repeating one or  
32       more times steps x), xi) and xii).

1 Moreover, the method may comprise the further step  
2 of:

3

4 xiv) visualising the steps of step xii).

5

6 According to the present invention it is  
7 advantageous that the method comprises the steps of  
8 installing, after step iv), in high stress areas, a  
9 first set of sensors for measuring the dimensions of  
10 the structure in said high stress areas.. Moreover,  
11 it is advantageous that the method comprises the  
12 step of installing, after step iv), in high stress  
13 areas, a second set of sensors for measuring the  
14 load on the structure in said high stress areas.

15

16 The advantage of these measures is the fact that the  
17 data relating to the dimensions of the structure and  
18 the actual load on the structure can be collected  
19 automatically. In order to process the collected  
20 data in real-time it is an advantage that the method  
21 comprises the step of connecting the sensors to  
22 processing means, such as a computer, for  
23 transmitting data from the sensors to the processing  
24 means in real-time.

25

26 The method according to the present invention can be  
27 used for new systems. The method, however, is also  
28 suitable for structures which already have been used  
29 during a certain time frame. In those cases it is  
30 advantageous that the method comprises the step of  
31 prior to step iv), collecting data relating to known  
32 defects of the structure and thereafter using said

1       defect-data, the computer model of the structure and  
2       the load-data for defining areas which are subject  
3       to relatively high loads.

4

5       By adding the data relating to known defects of the  
6       structure the calculation of high load areas in the  
7       structure can be refined. Deterioration and growth  
8       of the defects can then be measured and analysed.

9

10      In case there are no known defects, it is possible  
11      that the method comprises the step of prior to step  
12      iv), estimating the minimum size of defect in the  
13      structure and thereafter using said estimated  
14      defect-data, the computer model of the structure and  
15      the load-data for defining areas which are subject  
16      to relatively high loads. Moreover, it is possible  
17      that the minimum size of the defect is estimated to  
18      be equal to the precision the measurement equipment,  
19      used for measuring the dimensions of the structure.

20

21      When the structure, to be analysed, is used for a  
22      certain time period, and the load history on the  
23      structure is known, it is possible that the method  
24      comprises the step of prior to step iv), collecting  
25      data relating to the load-history on the structure  
26      and thereafter using said load-history, the computer  
27      model of the structure and the load-data for  
28      defining areas which are subject to relatively high  
29      loads. Using this extra step of collecting data  
30      relating to the load-history means that initial  
31      calculations of high-load areas can be refined.

32

1       The invention also relates to a processing  
2       arrangement for assessing the integrity of a  
3       structure, provided with processing means, such as a  
4       computer, for using data relating to the dimensions  
5       of the structure and the load on the structure in a  
6       calculation of a value representing the integrity of  
7       the structure, wherein the processing arrangement is  
8       provided with sensors to measure data relating to  
9       the dimensions of the structure and the load on the  
10      structure, the sensors being adapted to transmit  
11      said data in real-time, wherein the processing means  
12      are provided with receiving means for receiving said  
13      data and wherein the processing means are adapted to  
14      analyse the data in order to update the calculation  
15      of the value representing the integrity of the  
16      structure.

17  
18      Preferably the processing arrangement is provided  
19      with representation means for visualising the  
20      results of the calculation of the value for the  
21      integrity of the structure.

22  
23      According to the invention it is possible that the  
24      sensors used in the processing arrangement are  
25      adapted to measure pressure exerted on the  
26      structure, environmental loads, temperature,  
27      mechanical loading on the structure, fluid loading  
28      on the structure, vibration or acceleration  
29      experienced by the structure.

1       The invention also relates to a structure, such as a  
2       plant, provided with a processing arrangement as  
3       described above.

4  
5       The method according to the present invention can be  
6       entirely controlled by a suitable computer program  
7       after being loaded by the processing arrangement.  
8       Therefore, the invention also relates to a computer  
9       program product comprising data and instructions  
10      that after being loaded by a processing arrangement  
11      provides said arrangement with the capacity to carry  
12      out a method as defined above.

13  
14      Also a data carrier provided with such a computer  
15      program is claimed.

16  
17      Below, the invention will be explained in detail  
18      with reference being made to the drawings. The  
19      drawings are only intended to illustrate the  
20      invention and not to limit its scope which is only  
21      defined by the dependent claims.

22  
23      Fig 1 shows a schematic overview of a processing  
24      arrangement for assessing the integrity of a vessel.  
25      Fig 2 shows a visual representation of the  
26      calculations of a value for the integrity of a  
27      structure.

28  
29      Fig 3 shows a schematic overview of the software  
30      used according to the present invention.

1 Fig 4 shows a diagram indicating the relation  
2 between inspection costs, the number of inspections  
3 and the corresponding risk.

4

5 In Fig 1 a schematic overview is shown of a  
6 processing arrangement 10 for assessing the  
7 integrity of a vessel. In order to assess the  
8 integrity of the vessel 20, at an initial stage a  
9 computer model will be created representing the  
10 dimensions of the vessel 20. When creating said  
11 computer model the presence of corroded areas 21 and  
12 the presence of flaws, pits and cracks 22 can be  
13 taken into account. The processing arrangement 10  
14 comprises sensors 11 which are installed in high  
15 load areas of the vessel 20. In Fig 1 only one  
16 sensor is shown. In practice, several sensors will  
17 be installed in order to allow a good overview of  
18 the condition, strains and stresses in the vessel  
19 20. The sensor 11 by means of a line 12 is  
20 connected to a data logger 13. The data logger 13  
21 is connected to processing means 14, such as a  
22 computer. The computer 14 is provided with suitable  
23 software in order to process the data generated by  
24 the data logger 13. A possible architecture for the  
25 software to be used in the computer 14 is described  
26 with reference to Fig 3. By means of the sensor 11  
27 the actual dimensions of the vessel 20 and the load  
28 exerted on the vessel can be continuously measured  
29 and can be forwarded to the computer 14. The  
30 updated information sent to the computer 14 can be  
31 used to constantly reanalysis the structure and

1       recalculate values for the integrity of the  
2       structure.

3

4       The results of the calculations can be visualised,  
5       for instance by means of a document centre 15. The  
6       document centre 15 can be used, for instance, for  
7       printing tables and overviews (see Fig 2), in order  
8       to inform the responsible plant manager.

9

10      In Fig 1 reference numbers 23 and 24 are used for a  
11      graphic representation of flaws, pits and cracks  
12      which can be present in the vessel wall. During the  
13      lifetime of the vessel the actual size of such  
14      flaws, pits and cracks (in 3-d) will be used in  
15      calculations of the value for the integrity of the  
16      structure. That means that according to the present  
17      invention no estimations of trends are used. The  
18      actual sizes of the flaws, pits and cracks in the  
19      system will be used when calculating the  
20      representative value for the integrity of the  
21      structure.

22

23      According to the present invention it is possible to  
24      add a warning system. This warning system could  
25      produce a warning when the value for the integrity  
26      of the structure drops below a specific  
27      predetermined level. It is also possible to  
28      indicate on a visual representation the value for  
29      the integrity of the structure has dropped below a  
30      certain minimum.

31

1     In Fig 2 a possible outcome of the calculations are  
2     shown. According to the requirements of a user, the  
3     outcome of the calculations provides information on,  
4     but not limited to, the working pressure inside the  
5     vessel, the number of fatigue cycles to date, the  
6     number of fatigue cycles remaining, current  
7     corrosion rate, date until inspection is required,  
8     the current safety factor, current risk factors,  
9     etc. The visual representation of the outcome of  
10    the calculations of the value for the integrity of  
11    the structure can be tailored upon a user's request.  
12    The visual representation according to Fig 2  
13    provides a plant manager with a user-friendly  
14    overview of the integrity of a structure.

15  
16    In Fig 3 a schematic overview is given of a software  
17    program which can be used in the method and  
18    processing arrangement according to the present  
19    invention. Because of the fact that the software  
20    module provides an analysis system for plant real-  
21    time integrity assessment, the software module could  
22    be referred to as "Aspria". The software system is  
23    built up from several modules. The overall system  
24    will be referred to as "Integri-TECH".

25  
26    The layout of the software system is shown in Fig 3.  
27    The central part of the system is a so-called  
28    management system or core system. The core system  
29    manages and controls the components and will produce  
30    the visual representation as shown in Fig 2. The  
31    core system enables the different modules to work

1      together in order to produce a single outcome,  
2      representing the integrity of a structure.

3  
4      The core system comprises an analysis tool (Smart  
5      FEA), which is a program based on finite element  
6      analysis technology. This module includes advanced  
7      error estimation techniques. The module contains  
8      the "as-built" model of the structure to be  
9      analysed, plus components and receives the regular  
10     measurement data. When receiving the measurement  
11     data this module will update the finite element  
12     model and will perform an advanced finite element  
13     analysis and thereafter passes the results to  
14     further modules.

15  
16     The core system also comprises a module for  
17     assessment of a corrosion patch. This module can be  
18     referred to as "envelope corrosion patch assessment"  
19     (ECPA), which has been derived to assess the effects  
20     of patches of corrosion in the various regions of  
21     each structure to be analysed. The module generates  
22     an envelope of possible conditions that will allow  
23     the system to predict the earliest possible danger  
24     signs for each structure. The corrosion patches can  
25     be located and automatically updated every time a  
26     corrosion measurement is taken or can be  
27     automatically generated from measurement data,  
28     adaptively meshed and can be dynamically positioned  
29     anywhere on the structure to be analysed for  
30     detailed finite element analysis. The results of  
31     the analysis are modified to account for the most  
32     likely severe and emerging patch shape and where the

1 results are becoming nearer to limiting values,  
2 recommendations are passed back through the system  
3 in order that the finite element analysis can modify  
4 the finite element mesh in order to re-analysis the  
5 system whereby the corrosion patches are included.

6  
7 The core system further comprises a corrosion  
8 trending analysis (CTA). This modules analyses the  
9 history and trends and the future effects of  
10 corrosion and erosion in the system. This module  
11 moreover builds up on a history of the effects and  
12 derives continually updating correlations to predict  
13 corrosion rates, patterns, etc in order to be used  
14 in a further statistical analysis module.

15  
16 In case the structure to be analysed is in a high  
17 temperature area, for instance in high energy piping  
18 systems, a creep assessment system (CAS) can be  
19 used. This module will analyse the temperature and  
20 time history of a certain structure. Thereafter a  
21 creep analysis of the system will be carried out to  
22 simulate the stress changes due to time dependent  
23 temperature effects in the piping system and will  
24 build up a history of the effects and derive  
25 continually updating correlations to predict creep  
26 rates, patterns etc for the statistical analysis  
27 module.

28  
29 In case the structure to be analysed is subject to  
30 acoustic pulsation, such as in gas compression  
31 systems, a further harmonic-acoustic simulator (HIS)  
32 can be used. This modules analyses the acoustic

1        pulsations in the system by harmonic analysis to  
2        simulate the stress changes due to acoustic  
3        pulsations in the piping system. The history is  
4        then stored and trends are predicted for the future  
5        effects of acoustic pulsations in the system and the  
6        system builds up a history of the effects and  
7        derives continually updating correlations to predict  
8        cyclic stress patterns. These cyclic stress patterns  
9        can be used in a statistical analysis module.

10  
11      In case the structure to be analysed is subject to  
12      transient fluid flow conditions, such as in pumping  
13      systems, the core system moreover uses a transient  
14      simulator (TS). This module analyses the transient  
15      fluid flow effects in the system by time history  
16      analysis to simulate the stress changes due to  
17      transient fluid flow effects in the piping system.  
18      The history is then stored and trends predicted for  
19      the future effects of transient fluid flow effects  
20      in the system and the system builds up a history of  
21      the effects and derives continually updating  
22      correlations to predict cyclic stress patterns.  
23      These cyclic stress patterns can be used in a  
24      statistical analysis module.

25  
26      The core system moreover comprises a statistical  
27      analysis module. This module takes all of the  
28      piping system loading history, cyclic patterns,  
29      operational data, corrosion and erosion and B-Tech  
30      vibration data and trends. These data then are  
31      statistically analysed to provide realistic and  
32      meaningful loading for first time history data for

1       the defect and fracture module. The same  
2       information can be used in a fatigue life prediction  
3       module to predict the remaining lifetime of the  
4       structure before shutdown or failure. Standard  
5       statistical analysis is then employed in the system.

6

7       The core system moreover is provided with a module,  
8       adapted to receive "live measurements", including  
9       frequency data, measured live by accelerometers, at  
10      small bore branch connections. This module is  
11      referred to as "B-Tech. The B-Tech part of the  
12      system then performs..extensive mathematical  
13      correlations, algorithms and techniques to predict  
14      the effect of the vibration and more importantly to  
15      predict the fatigue life for the analysed structure  
16      automatically from the measured data. The module,  
17      if needed, can alert the user and can prevent  
18      failure. Another important part of this module is  
19      that the module isn't only capable of predicting the  
20      fatigue life from vibration, but will also predict  
21      which vibration excitation will cause problems for  
22      each particular arrangement and will indicate these  
23      vibration excitation if that level of vibration is  
24      detected.

25

26      Results of these calculations will then be passed to  
27      a further defect and fracture and FLP modules.

28

29      The core system moreover is provided with a liquid  
30      sloshing simulator. This module performs the  
31      simulation and assessment of liquid sloshing that  
32      can take place when a vessel is located on a moving

1       object, such as a ship. Such liquid sloshing is  
2       very detrimental to the integrity of the vessel and  
3       can be catastrophic. Therefore it is most important  
4       to assess the exact effects of the sloshing on the  
5       integrity of the vessel. The liquid sloshing  
6       simulator is adapted to simulate sloshing and to  
7       predict the interaction of the sloshing with the  
8       pressure vessel or a ship wall. The response of  
9       these loadings to the ship (or a vehicle) motion is  
10      measured and the cyclic loading pattern is generated  
11      and passed through the finite element analysis  
12      system for dynamic stress analysis. This analysis  
13      is followed by a defect and fatigue analysis in  
14      order to verify the integrity of the structure.

15  
16      The core system moreover comprises a defect and  
17      fracture module. This module performs the fracture  
18      mechanics assessment. The system is adapted to  
19      monitor, analyse and assess the growth of any defect  
20      in the structure. The system integrity is then  
21      quantified in respect of limiting crack and flaw  
22      sizes that will affect the integrity. The location,  
23      size and type of any possible defect or arrangement  
24      of cumulative defects can be assessed and also  
25      postulated defect assessments can be carried out.  
26      For instance, every well in a structure, is assessed  
27      and every range of defects is assessed at every  
28      weld.

29  
30      A further module present in the core system is the  
31      fatigue life prediction module (FLP). This system  
32      performs the fatigue life predictions.

1      The core system manages the various modules which  
2      are shown in Fig 3. The specific features of those  
3      six modules will be described below.

4

5      Aspria (analysis system for plant real time  
6      integrity assessment) is an analysis, monitoring and  
7      assessment system that can be connected to any  
8      pressurised plant or structural system than can  
9      deteriorate by erosion, corrosion or general  
10     time/operation exposure and/or vibration. This  
11     module quantifies the system's integrity, assesses  
12     the effects of all loadings, stresses, defects and  
13     predicts inspection and repair intervals as well as  
14     plant life and safety. This is all done "on-line",  
15     "live" or as "continuous monitoring system".

16

17     The Aspria module constantly measures geometric  
18     thickness values in piping systems effected by  
19     corrosion, erosion, vibration, etc. A detailed  
20     geometric update is performed and the unit, whether  
21     a piece of plant, such as pipework, a structure or  
22     similar, will undergo an automatic and complete  
23     finite element stress analysis using for instance  
24     Smart-FEA (see above) and advanced error estimation  
25     techniques to determine the degree of accuracy.  
26     Defects, cracks or corrosion patches will be  
27     thoroughly analysed automatically and a system  
28     fatigue life automatically calculated. This will  
29     lead to prescribed inspection and repair intervals,  
30     and a quantified plant life. All loadings,  
31     including process, mechanical and environmental  
32     loadings, will be included in the assessment. If

1       the structure is used on a ship, the loading will  
2       include sea motion.

3

4       The second module which can be used in the software  
5       is Vecor (vessel corrosion analysis system for plant  
6       real time integrity assessment). Vecor is an  
7       analysis, monitoring and assessment system that can  
8       be connected to any pressure vessel, tank or storage  
9       system which can deteriorate by erosion, corrosion  
10      or general time/operation exposure and/or vibration.  
11      The system includes FPSO and ship movements and the  
12      liquid sloshing and fluid structural interaction  
13      effect of vessels on ships. Moreover Vecor will  
14      include acceleration effects. It quantifies the  
15      system and integrity, assesses the effects of all  
16      loadings, stresses defects etc and predicts  
17      inspection and repair intervals as well as plant  
18      life and safety. This is all done "on-line", "live"  
19      or as a continuous monitoring system. The Vecor  
20      system will constantly measure geometric thickness  
21      values in pressure vessels, exchangers and tanks  
22      affected by corrosion, erosion, vibration etc.  
23      Another item that Vecor can measure is the motion of  
24      a ship or a platform. A detailed geometric and  
25      loading update will then be performed and the  
26      structure will undergo an automatic and complete  
27      finite element stress analysis using for instance  
28      Smart-FEA (see above) and advanced error measurement  
29      techniques in order to determine the degree of  
30      accuracy. Liquid sloshing effect within the vessel  
31      will be simulated and assessed if appropriate (that  
32      means when a ship pitches, heaves and rolls).

1      Interaction effects of the liquid sloshing and the  
2      vessel structure response will also be assessed.  
3      Defects, cracks or corrosion patches will be  
4      thoroughly analysed automatically and a system  
5      fatigue life automatically produced. This will lead  
6      to prescribed inspection and repair intervals, plus  
7      quantified plant life. All loadings, including  
8      process, mechanical and environmental loadings will  
9      be included in the assessments, including (if  
10     appropriate) sea motion.

11     A further module to be used in the system is HEP-  
12     TECH (high energy piping technology). HEP-TECH is  
13     an analysis monitoring and assessment system which  
14     can be connected to high energy or high temperature  
15     piping systems in power stations or other markets,  
16     where deterioration by creep, support load  
17     variation, load and stress redistribution, high  
18     temperature effects or general time/operation  
19     exposure and/or vibration occurs. It quantifies the  
20     system integrity, assesses the effects of all  
21     support behaviour, loadings, stresses, defects and  
22     predicts inspection and repair intervals as well as  
23     plant life and safety. This is all done "on-line",  
24     "live" or as "continuous monitoring system. The  
25     HEP-TECH will constantly measure support load values  
26     effected by deterioration and load redistribution  
27     due to high temperatures or creep. A detailed load  
28     update will then be performed and the pipework will  
29     then undergo an automatic and complete finite  
30     element stress analysis and advanced error  
31     estimation techniques to determine the degree of  
32     accuracy. The system will be assessed and the load

1 corrections required highlighted for adjustments,  
2 which should be made to ensure piping and structural  
3 integrity. Defects, cracks or potential areas for  
4 such will be thoroughly analysed automatically and  
5 the system fatigue life will be produced  
6 automatically. This will lead to a prescribed  
7 inspection and repair intervals, plus quantified  
8 plant life. The assessments will include all  
9 loadings such as process, mechanical and  
10 environmental loadings. The potential for "leak  
11 before break" will also be assessed.

12 .....

13 A further module is the AP-Tech (acoustic pulsation  
14 technology). AP-Tech is an analysis, monitoring and  
15 assessment system to monitor, predict, simulate and  
16 assess the effects and levels of acoustic energy  
17 waves and frequencies in process plant piping  
18 systems. It also assesses the levels of dynamic  
19 excitation and vibration of the piping system but  
20 also has a module to prevent and identify a solution  
21 to the majority of small bore bench connection  
22 stress, vibration and fatigue problems. AP-Tech  
23 quantifies the piping system integrity, assesses the  
24 effects of all pulsation and piping behaviour,  
25 dynamic and fluid loadings, stresses, defects and  
26 small bore branches and predicts inspection and  
27 repair intervals as well as plant life and safety.  
28 These are all done "on-line", "live" or as a  
29 "continuous monitoring system". The AP-Tech system  
30 would constantly measure life acoustic pulsation  
31 pressure waves and the associated frequency and  
32 vibration values effected by acoustic pulsation and

1 vibration, etc. The detailed dynamic loading update  
2 will then be performed and the pipework will undergo  
3 an automatic and complete dynamic finite element  
4 stress analysis. Moreover, error estimation  
5 techniques will be used in order to determine the  
6 degree of accuracy. AP-Tech will use either a  
7 pressure transducer or a non-intrusive method to  
8 measure acoustic pulsations. The system will be  
9 dynamically assessed, the acoustic pulsation  
10 simulated and the acoustic-dynamic-vibration load  
11 cycle pattern and subsequent fatigue life will be  
12 determined.. A computational fluid dynamic simulator  
13 will optionally be attached to allow a user to  
14 "visualise" the acoustic pulsation behaviour of the  
15 system. All necessary timescales and indications of  
16 work areas required will be produced "automatically"  
17 which should be made to ensure piping and structural  
18 integrity. Defects, cracks or potential for such  
19 will be thoroughly analysed automatically and the  
20 system fatigue life will be produced automatically,  
21 which will lead to prescribed inspection and repair  
22 intervals, plus a quantified plant life. All  
23 loadings, including process, mechanical, pulsation,  
24 acoustic, vibration and environmental loadings will  
25 be included in the assessment.

26  
27 A further module to be used in the system is F-Tech.  
28 This is a module which provides beneficial analysis  
29 and monitoring and assessment for the majority of  
30 piping and vessel-tank flange connections. The  
31 problems to monitor involve stress, vibration,  
32 leakage and fatigue. F-Tech quantifies the flange

1 joint integrity, assesses the effects of all flange  
2 loadings, gaskets, bolts, stresses and predicts  
3 inspection and repair intervals as well as plant  
4 life and safety. This is all done "on-line", "live"  
5 or as "continuous monitoring" system. F-Tech will  
6 provide a detailed geometric update of the monitored  
7 area and then the area will undergo an automatic and  
8 complete finite element stress analysis and advanced  
9 error estimation techniques to determine the degree  
10 of accuracy. Flange displacement and rotation will  
11 be assessed along with gasket seating pressure in a  
12 live and automatic mode.. This will be thoroughly  
13 analysed "automatically" and the system fatigue  
14 life, joint relaxation plus potential for joint  
15 leverage will be automatically produced. This will  
16 lead to prescribed inspection and repair intervals,  
17 plus quantified plant life. All loadings including  
18 process, mechanical and environmental loadings will  
19 be included in the assessment.

20

21 A further module to be used is called Trans-Tech.  
22 This module is adapted to monitor, predict, simulate  
23 and assess the effects of the majority of piping  
24 transient events such as fluid transient and energy  
25 waves and frequencies in process plants piping  
26 systems. It also assesses the levels of dynamic  
27 excitation and vibration of the piping system.  
28 Moreover, Trans-Tech has a module to prevent and  
29 identify a solution to the majority of small bore  
30 branch connections stress, vibration and fatigue  
31 problems. Trans-Tech quantifies the piping system  
32 integrity, assesses the effects of all fluid

1 transient and piping behaviour, dynamic and fluid  
2 loadings, stresses, defects, small bore branches and  
3 thereafter predicts inspection and repair intervals  
4 as well as plant life and safety. This is all done  
5 "on-line", "live" or as a "continuous monitoring"  
6 system. A computation fluid dynamic simulator will  
7 optionally be attached to allow clients to visualise  
8 the acoustic pulsation behaviour of the system. All  
9 necessary timescales and indications of work areas  
10 required will be produced automatically which should  
11 be made to ensure piping and structural integrity.

12  
13 All six modules, described above, have the option of  
14 utilising accelerometers to include the effects of  
15 system vibration. All systems have preset intervals  
16 for the automatic measurement readings and  
17 subsequent re-analysis. This is determined by the  
18 user and could be adapted in order to analyse and  
19 measure every hour all day, or any other time  
20 interval. The cost of the modular architectural  
21 software the Integri-Tech system can be set up for  
22 any structure, any piece of plant, pressure vessels,  
23 equipment, civil buildings, structures, ships and  
24 buried pipes.

25  
26 In order to collect the data to be processed by the  
27 software as described above the processing  
28 arrangement according to the present invention uses  
29 measurement hardware components which will include:  
30  
31 Ultrasonic thickness, ultrasonic blanket thickness  
32 measuring devices, accelerometers, data transmittal

1 devices, data interface devices, acoustic  
2 measurement systems, pressure transducers, non-  
3 intrusive PVDF systems, pipe support load  
4 measurement cells, strain gauges, ground settlement  
5 gauges, gyroscopes and ship-vehicle motion devices,  
6 acoustic emission systems, patch corrosion  
7 measurement devices, radiography interfaces, MAP  
8 scan interfaces, intelligent pigging interfaces, and  
9 crack growth measurement devices.

10  
11 The advantages of using the system according to the  
12 present invention include:

13  
14 The generation of information to protect inspection  
15 and remedial action plans. Since all necessary  
16 information on the critical areas of a structure are  
17 known, the use of the system will lead to a  
18 reduction of risks and a reduction of inspection  
19 costs. Moreover, the system provides real time  
20 information on the integrity of the system, which  
21 enables prompt action if required.

22  
23 In Fig 4 the possible advantages of the system  
24 according to the present invention are shown. Line  
25 X represents the amount of costs involved with a  
26 respective number of inspections. Line Y represents  
27 the relation between possible risks and the number  
28 of inspections. Line Z represents a modified  
29 relation between risks involved and the number of  
30 inspections when using the system according to the  
31 present invention.

1      Fig 4 shows that using the system according to the  
2      present invention will lead to a lower level of  
3      risk, while at the same time the number of  
4      inspections (meaning the costs involved as  
5      inspections) will decrease.

1    CLAIMS  
2

3    1. Method for assessing the integrity of a  
4    structure, comprising the steps of:

5

6    i) collecting data relating to the initial  
7    dimensions of the structure,  
8    ii) creating a computer model of the structure,  
9    iii) collecting data relating to the estimated load  
10   on the structure,  
11   iv) analysing the structure, using the computer  
12   model of the structure and the load data, in  
13   order to define areas which are subject to  
14   relatively high stresses,  
15   v) measuring, after a time interval, the  
16   dimensions of the structure in high stress  
17   areas,  
18   vi) updating the computer model of the structure,  
19   using the results of step v),  
20   vii) re-analysing the structure, using the updated  
21   computer model and the load data, in order to  
22   calculate a value for the integrity of the  
23   structure.

24

25   2. Method according to Claim 1, wherein the method  
26   comprises the step of:

27   viii) repeating one or more times steps v), vi) and  
28   vii).

29

30   3. Method according to Claim 1 or 2, wherein the  
31   method comprises the step of:

32   ix) visualising the results of step vii).

1     4. Method according to Claim 1, 2 or 3, wherein the  
2     method comprises the steps of:

3       x) measuring the actual load on the structure,  
4       xi) updating the data relating to the load on the  
5       structure, and thereafter  
6       xii) re-analysing the structure, using the computer  
7       model and the updated load data, in order to  
8       calculate a value for the integrity of the  
9       structure.

10

11     5. Method according to Claim 4, wherein the method  
12     comprises the step of:  
13       xiii) repeating one or more times steps x), xi) and  
14       xii).

15

16     6. Method according to Claims 4 or 5, wherein the  
17     method comprises the step of:  
18       xiv) visualising the results of step xii).

19

20     7. Method according to one of the preceding claims,  
21     wherein the method comprises the step of installing,  
22     after step iv), in high stress areas, a first set of  
23     sensors for measuring the dimensions of the  
24     structure in said high stress areas.

25

26     8. Method according to one of the preceding claims,  
27     wherein the method comprises the step of installing,  
28     after step iv), in high stress areas, a second set  
29     of sensors for measuring the load on the structure  
30     in said high stress areas.

31

1       9. Method according to Claim 7 or 8, wherein the  
2       method comprises the step of connecting the sensors  
3       to a processing means, such as a computer, for  
4       transmitting data from the sensors to the processing  
5       means in real time.

6

7       10. Method according to one of the preceding claims,  
8       wherein the method comprises the step of prior to  
9       step iv), collecting data relating to known defects  
10      of the structure and thereafter using said defect-  
11      data, the computer model of the structure and the  
12      load-data for defining areas which are subject to  
13      relatively high loads.

14

15      11. Method according to one of the preceding claims,  
16      wherein the method comprises the step of prior to  
17      step iv), estimating the minimum size of defects in  
18      the structure and thereafter using said estimated  
19      defect-data, the computer model of the structure and  
20      the load-data for defining areas which are subject  
21      to relatively high loads.

22

23      12. Method according to Claim 11, wherein the  
24      minimum size of the defects is estimated to be equal  
25      to the precision of the measurement equipment, used  
26      for measuring the dimensions of the structure.

27

28      13. Method according to one of the preceding claims,  
29      wherein the method comprises the step of prior to  
30      step iv), collecting data relating to the load-  
31      history on the structure and thereafter using, said  
32      load-history, the computer model of the structure

1 and the load-data for defining areas which are  
2 subject to relatively high loads.

3

4 14. Processing arrangement for assessing the  
5 integrity of a structure, provided with processing  
6 means, such as a computer, for using data relating  
7 to the dimensions of the structure and the load on  
8 the structure in a calculation of a value  
9 representing the integrity of the structure, wherein  
10 the processing arrangement is provided with sensors  
11 to measure data relating to the dimensions of the  
12 structure and the load on the structure, the sensors  
13 being adapted to transmit said data in real-time,  
14 wherein the processing means are provided with  
15 receiving means for receiving said data and wherein  
16 the processing means are adapted to analyse the data  
17 in order to update the calculation of the value  
18 representing the integrity of the structure.

19

20 15. Processing arrangement according to Claim 14,  
21 wherein the processing arrangement is provided with  
22 representation means for visualising the result of  
23 the calculation of the value representing the  
24 integrity of the structure.

25

26 16. Processing arrangement according to Claim 14 or  
27 15, wherein the sensors are adapted to measure  
28 pressure exerted on the structure.

29

30 17. Processing arrangement according to Claim 14 or  
31 15, wherein the sensors are adapted to measure  
32 temperature.

1    18. Processing arrangement according to Claim 14 or  
2    15, wherein the sensors are adapted to measure  
3    mechanical loading on the structure.

4

5    19. Processing arrangement according to Claim 14 or  
6    15, wherein the sensors are adapted to measure fluid  
7    loading on the structure.

8

9    20. Processing arrangement according to Claim 14 or  
10   15, wherein the sensors are adapted to measure  
11   vibration.

12 ..

13   21. Processing arrangement according to Claim 14 or  
14   15, wherein the sensors are adapted to measure  
15   acceleration experienced by the structure.

16

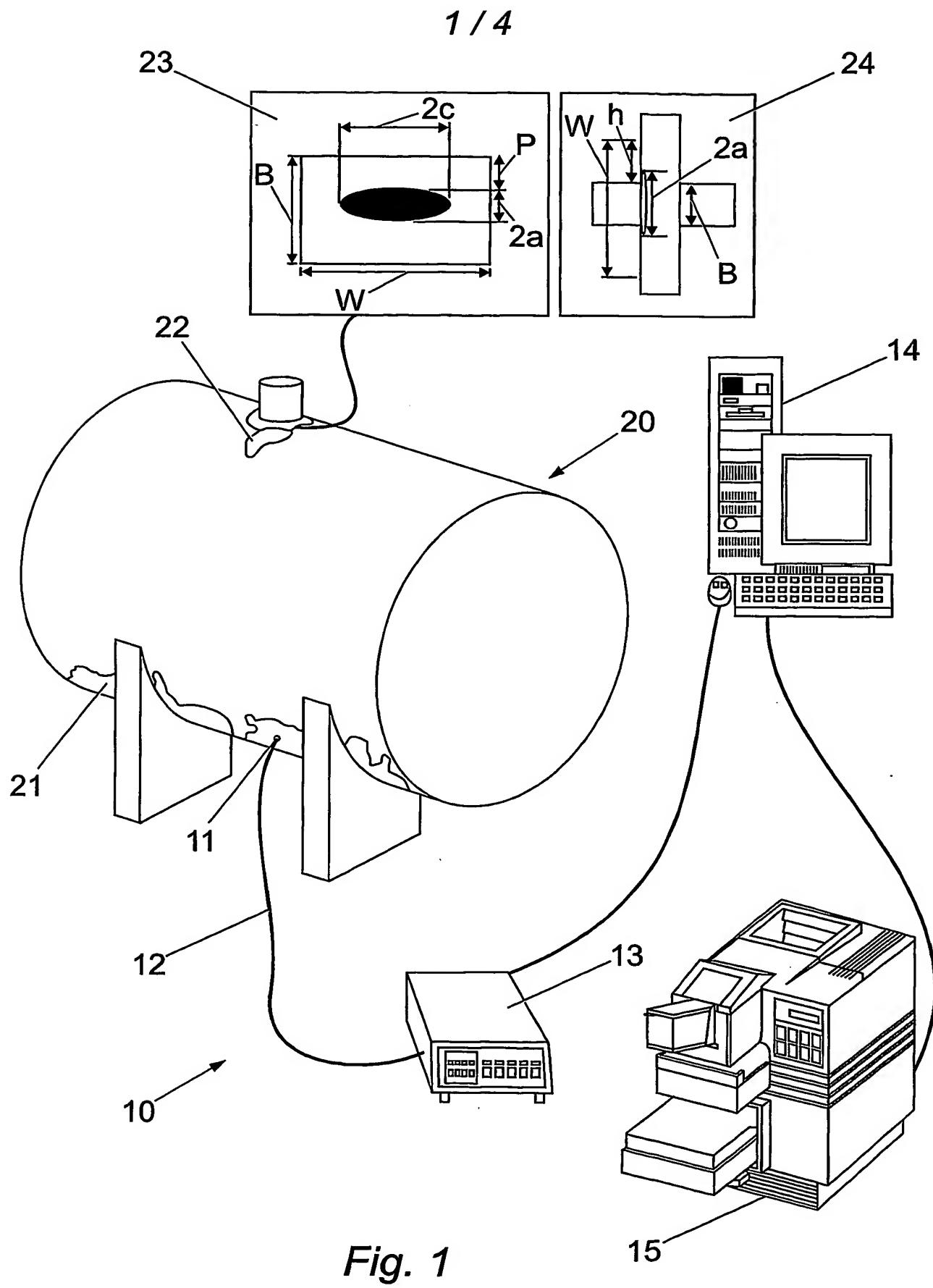
17   22. Structure, such as a plant, provided with a  
18   processing arrangement according to Claims 14-21.

19

20   23. A computer program product comprising data and  
21   instructions that after being loaded by a processing  
22   arrangement provides said arrangement with the  
23   capacity to carry out a method according to Claims  
24   1-13.

25

26   24. A data carrier provided with a computer program  
27   product according to Claim 23.



*Fig. 1*

2 / 4

Client - IDEAS Ltd

System - VECTOR

Subject - Sample Report - First Stage Separator

Date - 04/03/02

Factor	Value	Units
Safe Combined Working Pressure	38.13	Barg
Individual Flaw Maximum Pressure	35.72	Barg
Individual Flaw group Maximum Pressure	32.12	Barg
Estimate of Tolerable Flaw Size	4.51	mm
Number of Fatigue Cycles to Date	1.09E+11	Cycles
Number of Fatigue Cycles remaining	4.47E+09	Cycles
Current Corrosion Rate	0.97	mm/year
Number of Fatigue Days remaining	1.03E+03	Days
Number of Fatigue Years remaining	2.83	Years
Days until Inspection & NDT required	517.36	Days
Years until Inspection & NDT required	1.42	Years
Days until Remedial Action requires	724.31	Days
Years until Remedial Action requires	1.98	Years
Current Safety Factor	2.14	
Current Risk Factor	0.47	

System is Fit for Purpose until Inspection &amp; NDT Required

*Fig. 2*

3 / 4

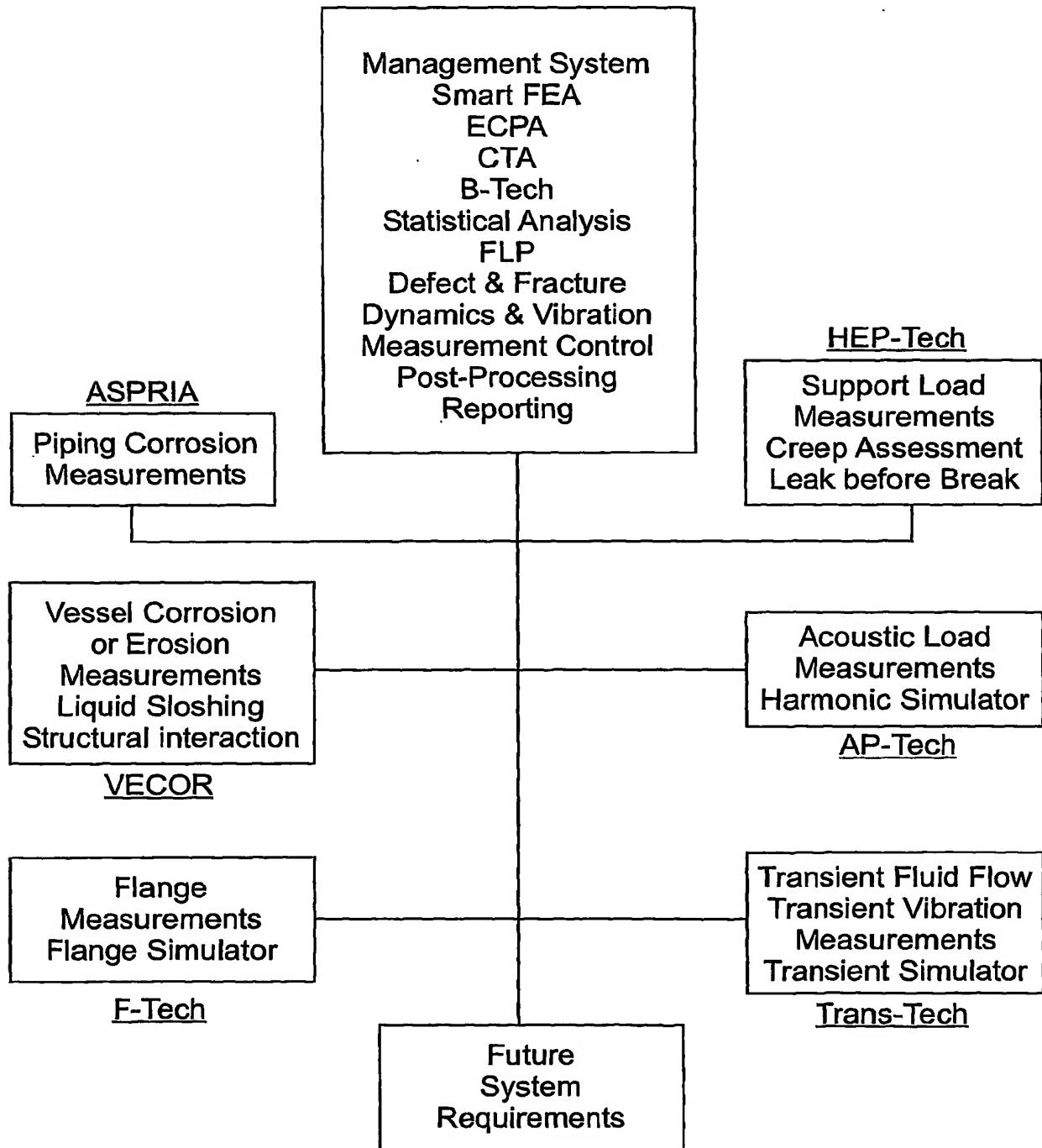
CORE SYSTEM

Fig. 3

4 / 4

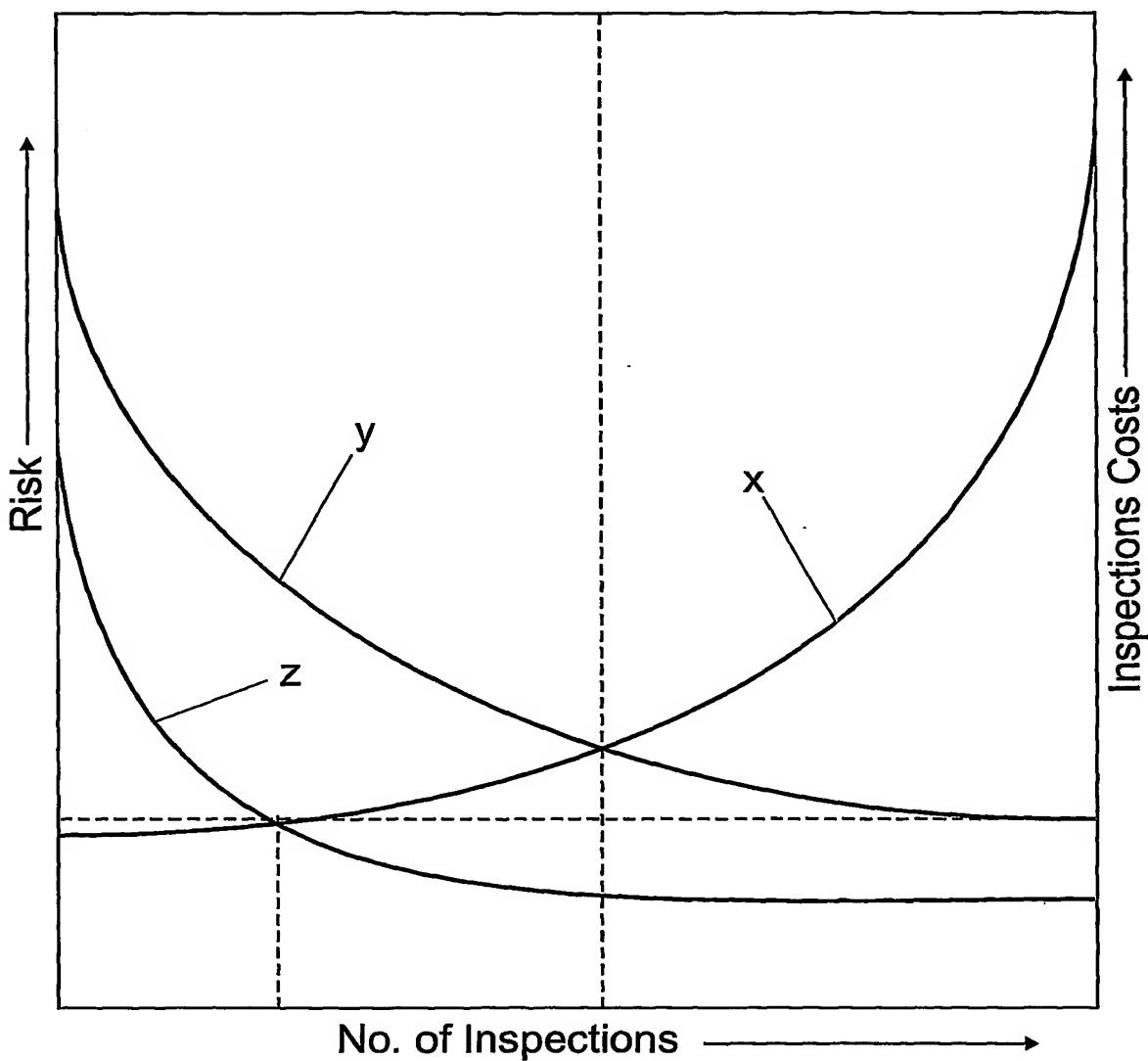


Fig. 4

## INTERNATIONAL SEARCH REPORT

Internal Application No  
PCT/GB 03/00868

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 G05B23/02 G05B17/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 G05B G01N G01H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 852 397 A (HAGGAG FAHMY M) 1 August 1989 (1989-08-01)	14,15, 18,22
Y	column 15, line 21 - line 62; figure 9 ----	1,16,17, 20
Y	US 6 047 241 A (SPARAGO MICHAEL T) 4 April 2000 (2000-04-04) column 13, line 26 -column 14, line 47 ----	1
Y	US 6 134 485 A (TANIELIAN MINAS H ET AL) 17 October 2000 (2000-10-17) column 5, line 11 - line 44 ----	16,17
Y	US 4 419 900 A (SCOTT DAVID R ET AL) 13 December 1983 (1983-12-13) column 5, line 27 -column 6, line 2 ---- -/-	20

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

## ° Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
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- \*P\* document published prior to the International filing date but later than the priority date claimed

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- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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- \*&\* document member of the same patent family

Date of the actual completion of the International search

Date of mailing of the International search report

16 June 2003

24/06/2003

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Authorized officer

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## INTERNATIONAL SEARCH REPORT

Internal Ref.	Application No.
PCT/GB	00868

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 358 994 A (WESTINGHOUSE ELECTRIC CORP) 21 March 1990 (1990-03-21) cited in the application column 2, line 52 -column 5, line 13 ---	1,14
A	US 6 341 258 B1 (KONNO TAKAO ET AL) 22 January 2002 (2002-01-22) claim 1 ---	1,14
A	GB 2 021 261 A (RES ANALYSIS & DEV) 28 November 1979 (1979-11-28) page 2, line 82 -page 3, line 33 ---	1,14
A	US 2001/040997 A1 (SARKAR SUDEEP ET AL) 15 November 2001 (2001-11-15) column 2, line 16 -column 3, line 6 ---	1,14
A	WO 02 01172 A (BRENNAN FEARGAL PETER ;UNIV LONDON (GB)) 3 January 2002 (2002-01-03) ---	

## INTERNATIONAL SEARCH REPORT

Internal Application No  
PCT/GB/00868

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 4852397	A	01-08-1989	NONE			
US 6047241	A	04-04-2000	NONE			
US 6134485	A	17-10-2000	NONE			
US 4419900	A	13-12-1983		US 4287511 A 01-09-1981 JP 58144725 A 29-08-1983 DK 444880 A 23-04-1981 EP 0027738 A2 29-04-1981 JP 1599844 C 31-01-1991 JP 2022438 B 18-05-1990 JP 56153492 A 27-11-1981 NO 803137 A 23-04-1981 PT 71943 A ,B 01-11-1980 US 4398184 A 09-08-1983		
EP 0358994	A	21-03-1990		US 4935195 A 19-06-1990 EP 0358994 A1 21-03-1990 ES 2065955 T3 01-03-1995 JP 2114149 A 26-04-1990		
US 6341258	B1	22-01-2002		JP 2000266632 A 29-09-2000 US 2002059034 A1 16-05-2002		
GB 2021261	A	28-11-1979		AU 4688079 A 15-11-1979 BE 876171 A1 12-11-1979 BR 7902765 A 27-11-1979 DE 2918886 A1 20-12-1979 FR 2425627 A1 07-12-1979 IL 57235 A 31-07-1983 IN 151971 A1 17-09-1983 IT 1112859 B 20-01-1986 JP 54151299 A 28-11-1979 NL 7903628 A 13-11-1979 NO 791554 A 13-11-1979 NZ 190374 A 17-08-1982 SE 7904034 A 11-11-1979		
US 2001040997	A1	15-11-2001		AU 5442800 A 18-12-2000 WO 0073973 A1 07-12-2000		
WO 0201172	A	03-01-2002		GB 2364127 A 16-01-2002 AU 6771201 A 08-01-2002 EP 1299700 A1 09-04-2003 WO 0201172 A1 03-01-2002		